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APPRAISAL OF EXISTING RESOURCES, USES AND REQUIREMENTS AND ALLOCATION TO DIFFERENT USES WITH PARTICULAR REFERENCE TO INDIA

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APPRAISAL OF EXISTING RESOURCES, USES AND REQUIREMENTS AND ALLOCATION TO DIFFERENT USES WITH PARTICULAR REFERENCE TO INDIA

by

Balwant Singh Nag

Ignoring the small utilisation of converted fresh water from sea water for municipal and industrial uses, precipitation in the form of rainfall or snowfall constitutes the primary source of water in any country. The eternal cycle of evaporation, cloud formation and precipitation plays the vital role of annual replenishment of water resources that get used or lost and thus nature maintains the balance. Where rainfall is plentiful, water resources are ample though they may not necessarily lend themselves to economic or full exploitation. In making an appraisal of water resources, it is more important to know the portion which can be put to beneficial use rather than the total quantity.

RAINFALL AND SNOWFALL

2. The sub-continent of India, which lies partly in tropical and partly in sub-tropical region and where land heights vary from sea level to very high mountains, has a wide range of rainfall varying from about 5 inches (130 mm) in the desert on the north-west to over 400 inches (10,160 mm) in the Cachar hills of Assam. The average rainfall of India is 41 inches (1041 mm) .Most of the rainfall is concentrated in the monsoon months of June to September when the south-west monsoon brings general, though not continuous, rainfall through out the country. The total rainfall of this period is about 100 inches (2,540 mm) over part of the west coast; the amount diminishes eastward to below 30 inches (760 mm) over a large part of the central and eastern Peninsula; it is over 100 inches (2,500 mm) in the north Assam valley and diminishes steadily westward, to only about 5 inches (130 mm) in the western part of Rajasthan. The contribution of north-east monsoon which lasts from October to December, is comparatively small and is confined primarily to peninsular India. There is practically no rainfall in the country for the rest of the year. There is not only marked variation in rainfall from one part of the country to another but also from year to year. It is not uncommon in many places for rainfall in a year to be less than half the normal, and in some cases, even much less during critical periods in crop growth when water is needed most.

3. The contribution from snowfall is confined to the Himalayan mountains which stretch over a length of 1500 miles (2415 km) along the northern boundary of the country. There are about 50 peaks with heights exceeding 24,000 feet (7315 metres) and these high altitudes are the abodes of numerous glaciers which give rise to perennial rivers flowing through the vast plains of

northern India. December to February is the snow accumulation season in these mountains. Precipitation occurs at intervals throughout this period, generally in the form of snow at higher levels, snow and rain in the lower hills and some rain over the adjoining plains. As this precipitation is caused by a series of weather disturbances which cross into northern India from the west and travel eastwards along the Himalayas, the precipitation decreases from west to east upto Sikkim, from where it increases to a certain extent, probably because of some additional moisture which becomes available on account of nearness of the sea. Temperature in these mountains starts rising in March. From this month to May or June is the snow-melt season when a very large proportion of the winter snow-cover melts away and contributes to the flows of the snow-fed rivers. While the melting of snow continues during the monsoon season, June to September, its contribution forms an insignificant fraction of the flood flows brought about by abundant rainfall during this period. For the remaining months October to November, the discharge of these rivers is made up almost entirely of ground water. It has been broadly computed that the percentage contribution from snow to the river runoff during the snow-melt season ranges between 20 to 90 per cent in the western rivers like the Jhelum and the Sutlej, to less than 5 per cent in the eastern rivers like the Gandak and the Teesta. Viewed for the year as a whole, the contribution from snow-melt is, therefore, not large, although it augments the river supplies in the dry months of March to June and provides the much-needed water for irrigation.

EVAPORATION AND OTHER LOSSES

4. Of the quantity of water which is annually contributed by rainfall, a good deal is lost through evaporation and transpiration. Also, there are losses into the subsoil, but what goes into the ground at any time reappears to a large extent as regeneration water ultimately. Unless, therefore, leakages occur from one catchment to another, the ground water loss can be ignored in determining the average water yield of a catchment area. Temperature plays a dominant role in the rate of evaporation and transpiration in a catchment area. Sunshine, clouds, wind velocity and humidity are also relevant but these generally follow the temperature cycle, and by and large can be taken to be represented by it. The mean annual loss, measured in terms of depth in inches, varies in different river basins of India from about 29 inches (740 mm) for rivers falling into the Bay of Bengal other than the Ganga and the Brahmaputra, to about 13 inches (330 mm) for Indus Basin lying in India. In Rajputana, the entire annual rainfall which is a meagre 11.5 inches (290 mm) is lost through evaporation and transpiration.

5. Evaporation from snow, because of low temperatures in the snow regions, is relatively small, being of the order of 0.1 inch (2.54 mm) per month at 0° F (-18°C) and 1.5 inches (41 mm) per month at 32° F (0° C). Above this temperature, the rate of evaporation progressively increases, but is a small percentage of the rate of snow-melt. For instance, while snow-melt at 72° F (22°C) is of the order of 60 inches (1524 mm) per month, evaporation is only about 7 inches (178 mm).

SURFACE WATER RESOURCES OF INDIA

6. Nature has blessed India with vast and bountiful water resources, both surface and ground water. The annual precipitation over the entire country represents something more than 3,000 million acre feet (37,000 mhcm) of water. As has been mentioned earlier, a good deal of it is lost through evaporation and transpiration. A part of it soaks into the ground to re-appear as regeneration flow. The first attempt at appraisal of the overall river water resources of India was made in 1949. In the absence of actual observed data for most rivers, this appraisal was based on an empirical formula which Dr. A.N. Khosla had evolved on the basis of his concept that annual or seasonal runoff is the residual of rainfall after deduction of evaporation and transpiration losses, and that the mean temperature is a complete measure of all the various factors affecting the evaporation and transpiration losses. The shape of the catchment, the slope and vegetal cover would have an effect on the seasonal distribution of runoff, but not on the aggregate runoff. The formula is:

$$R = P - \frac{T-32}{9.5}$$

where R = runoff (inches)
P = rainfall (inches)
T = mean temperature (degrees Fahrenheit)

Generally, T is taken as the mean monthly temperature. If the loss $L = \frac{Tm-32}{9.5}$ is calculated for monthly mean temperatures, the monthly losses can be aggregated to give the seasonal or the annual losses, and with corresponding figures used for the rainfall P, the corresponding monthly, seasonal or annual runoff can be determined. On the basis of the above formula, the result of the computations that were made was as under:-

(a)	Total catchment area of all the rivers	1,430,937 sq. miles (370,46,96 km^2)
(b)	(i) Normal annual rainfall	41.03" (1042 mm)
	(ii) Equivalent quantity of water.	3130 maft (38609 mhcm)
(c)	(i) Evaporation losses	23.26" (591 mm)
	(ii) Equivalent quantity of water	1774 maft (21882 mhcm)
(d)	(i) Annual runoff	17.77" (451 mm)
	(ii) Equivalent quantity of water	1,356 maft (16726 mhcm)

For the purpose of making estimates of the water resources of the various river basins, the country was divided into six major regions. These regions, the aggregate catchment areas of the riversin each and their computed runoff are stated below:-

Rivers	Total catchment area(sq.miles)	Runoff (maft)
(a) Rivers falling into Arabian sea (excluding the Indus system)	189,790	252
(b) Indus basin (in India)	136,673	64
(c) Rivers falling into Bay of Bengal, other than Ganga and Brahmaputra systems	460,309	334
(d) Ganga system	376,818	397
(e) Brahmaputra system	195,460	309
(f) Rajputana	64,887	-
Total:	1,430,937 ($37,046,96$ km^2)	1356 (16726 mhcm)

DEPENDABLE ASSESSMENT OF SURFACE WATER RESOURCES

7. Empirical formulae for the assessment of water resources have their value where actual reliable data over a period are not available, but these are no substitute for actual observations. In making an assessment of water resources, it is not sufficient only to determine the supplies of water in the river, but also the extent to which these supplies are available at the right time and place and whether they are susceptible of being conveyed and distributed over any desired area by economic projects. No large water resource development project can be based with a degree of reliability and confidence in the absence of adequate and satisfactory record of rainfall, runoff and flood data. The availability of water at any location alters with changes in utilisation and other conditions upstream. It is, therefore, essential to have continuous and long-range measurements of available water in order to assess its daily, weekly, monthly or annual mean values with the desired degree of accuracy and reliability. A system of well-equipped hydrological stations is a pre-requisite to planning water resources development projects.

8. The essential data that are required for making an estimate of the water resources of a river basin are :-

(a) Topographical maps of the entire river basin.
(b) Gauge, discharge and silt data.
(c) Locations of rain gauge stations and record of precipitation.
(d) Temperature and humidity records.
(e) Geological reports.
(f) Snow survey data if there is snowfall in the catchment.

Toppgraphical maps generally furnish a large part of the necessary reconnaissance data and aid in determining the extent of field work and investigations which are required to be carried out. Aerial photographs, where available, are helpful in providing information about cultivated area, vegetal cover, geological formations, etc. Gauge and discharge data are required to assess the quantum of water available at a particular site and the best manner of controlling, regulating and utilising it. The gauge discharge studies should also cover the flood history of the river for determining peak discharges, hydrographs and frequency of occurrences. A correct knowledge of the probable rate of silting in a river basin is a matter of vital concern for any undertaking dependent on stored supplies. The silt yield of a catchment depends upon the quantity, intensity and pattern of rainfall, the slopes of the terrain, the nature and extent of vegetal cover and the type of soil. Rain gauge stations should be situated in representative locations and there should be an adequate number of these in a catchment area, as otherwise, misleading results can arise. Apart from the knowledge of the total rainfall at a given station, it is important to know the rainfall intensities for various durations.

9. The accuracy of the assessment of water resources in a river basin will depend on the consistency reliability and adequacy of the data which may be available. The gauge and the discharge data should be scrutinised in respect of the methods of observation and the nature of the measuring equipment used and the method of computations adopted. Before using rainfall records for computing runoff flows, it is necessary to scrutinise whether the period of record has been continuous, the locations of the rain gauge stations have not been altered during the period and other indeterminate instrumental and observational errors have not crept in.

10. An important aspect to be considered is the loss of water due to seepage and transmission and the gain through direct return flow of part of the used water and on account of regeneration. Return flow from irrigation may amount to as much as 30 to 60 per cent of the irrigation water supply. The re-generated water can be used again on projects located downstream. Again, in the case of domestic water supply, a portion returns to the ground or to the stream as sewage with or without treatment. Re-use of such water for certain purposes depends on the degree of pollution and the treatment accorded to it. Similar is the case with water used in industry. Here the major requirement is for cooling purposes and a large portion of cooling water returns to the river or is available for re-use. It is, therefore, necessary to make an estimate of water actually consumed and the portion that may return to the ground or the stream in useable quality when making an assessment of the water resources of a basin.

11. The study of water resources of a river basin involves the following steps:-

(a) An assessment of the existing quantum of water consumptive utilisation on various projects and schemes.

(b) An assessment of the additional surface water requirements for consumptive uses for full development of existing projects.

(c) An assessment of absorption and transit losses and return flow from regeneration both under existing conditions and with additional appropriation for full development of existing projects.

(d) An assessment of evaporation losses from reservoirs, canals and river basins.

For forecasting the residual water resources in a river basin after the existing planned projects have reached full development, it is necessary to predict, if possible, the trend of future changes in losses and gains with a view to determining the cumulative effects under the changed hydraulic conditions of the river. Drastic changes in the hydrologic conditions of the river system will cause consequential changes in the quantum of loss and gain, and these would be important in appraising the river supplies for future needs.

UTILISATION OF SURFACE WATER RESOURCES

12. The surface water resources in a country can be put to a variety of uses such as irrigation, domestic and industrial water supply, hydro-electric power generation, navigation, river conservancy, reclamation of saline lands and salinity control in coastal areas. In considering the utilisation of river waters, distinction has to be made between consumptive and non-consumptive uses. Irrigation is regarded completely as a consumptive use although part of the water applied to irrigated lands may re-appear through seepage as regenerated water. Water used for municipal purposes as also in industries is partly returned back to the stream or is other-wise usable for other purposes, after proper treatment. Hydro-electric generation does not involve any appreciable consumptive use of water, although where storage is created for power generation, the evaporation loss from the reservoir reckons against consumptive use.

13. India has predominantly an agricultural economy, and as such irrigation assumes great importance in its development. Irrigation has been practised in the country since times immemorial. The nature of irrigation works adopted for utilising surface waters was determined by the pattern of flow in the river systems tapped. For instance, in north India with numerous snow-fed perennial rivers, the earlier irrigation projects were mostly river diversion works. For irrigating larger areas, where run-of-the-river flows during the

non-monsoon period have been found inadequate, it has in recent times been necessary to build storage works. In the southern part of the country where river flows dwindle in summer months, the practice of storing water in irrigation tanks during the monsoon period came into vogue. There are about 100,000 such tanks in this part of the country, some of which date back to many centuries. From their very nature, these tanks irrigated a relatively small block of area each. The replenishment of water in these tanks depends on the rainfall which, in zones of low rainfall is mostly erratic. These tanks, therefore, often fail to fill up in periods of drought when water is needed most. Some of the larger storage projects taken up in recent years, however, promise a more dependable source of irrigation as, with their larger catchments, the effect of local vagaries of rainfall is greatly evened off.

14. Hydro-electric power is generally a very cheap source of energy as no fuel consumption is involved. In 1953, the Central Water and Power Commission undertook the task of systematically assessing the total hydro-power potential of India, based primarily on a study of topographical maps and of available data on rainfall, run-off and river gauging. Allowance was made for other uses of waters of these rivers. A total hydro-electric potential of about 41 million kW has been assessed as technically and economically feasible. When field investigations are made, this figure is likely to be exceeded. Of this considerable hydro-power potential available in the country, only about 1.9 million kW had been developed by 1961. By the beginning of 1966, however, this development is likely to be increased to 5.1 million kW.

15. No large scale use is at present being made of river waters for reclaiming saline lands. In the coastal reaches, however, large flood flows during the monsoon period help in keeping in check the upland movement of salinity. In certain States such as West Bengal and Kerala, there are serious problems of salinity and projects have been planned with salinity control as an important object.

16. As has been stated earlier, the available river water resources of India have been computed at about 1356 million acre feet(16726 mhcm). But not all this water can be put to beneficial use. On certain rivers, while plenty of water is available, conditions are not conductive for its use. The Brahmaputra river system with its annual run-off exceeding 300 million acre feet (3701 mhcm) is an outstanding example. Because of high rainfall in the Brahmaputra Valley and its narrow average width of about 55 miles, there is neither sufficient land nor any appreciable demand for irrigation in the area. Elsewhere and notably in the Peninsula, there is not enough water in certain rivers to meet the requirements. It has broadly been estimated that, out of the computed surface water resources of 1356 million acre feet (16726 mhcm), only about 450 million acre feet (5550 mhcm) are utilisable for irrigation. By the beginning of 1961, only about 120 million acre feet (1480 mhcm) were being utilised. By 1966, an additional 40 million acre feet (493 mhcm) are likely to be used for this purpose.

GROUND WATER RESOURCES

17. Although the ground water resources of India are not as large as its surface water resources, from many considerations they are no less important. In areas where there is paucity of surface water, ground water resources, assume special significance. No dependable assessment has yet been made of these resources. Certain parts of the country, such as the Indo-Gangetic basin with its water-bearing stratum extending to a depth of several thousand feet, are known to be rich in this resource. Over the past eight years, a nation-wide survey of underground resources by means of extensive deep exploratory drilling has been undertaken. The results have been encouraging. The most significant discovery has been in the water-starved district of Jaisalmer in Rajasthan with an annual rainfall of less than 10 inches (254 mm), where a borehole has yielded a flow of 51,000 gallons per minute (232 kl per min), bringing new hope in an area where there has been scarcity of water even for drinking purposes. Very promising discoveries have been made in several other parts of the country. These exploratory operations for assessing ground water potentialities are continuing in various regions covering an aggregate area of about 136,000 sq. miles (352,240 km^2). For selecting individual sites for exploration, a reconnaissance survey is normally carried out guided mainly by geological conditions and also by the results of the geo-physical traverses carried out in the area.

18. Generally, an appraisal of ground water resources should cover a study of ground water table, location and extent of underground storage, yield, movement or distribution within the water-bearing formations and determination of the changes that take place in the natural course of events or as a result of interference. The replenishment of underground water in a basin is primarily due to the contribution from surface water and, in rare cases, from leakage of underground water from a neighbouring basin. If, either due to excessive irrigation or intensified absorption of flood waters on account of obstructed waterway and poor drainage, more water is added to the sub-soil than is withdrawn for various uses, it results in the progressive rising of the ground water table. This, in course of time, can cause water logged conditions leading to large-scale deterioration of land, thereby throwing large areas out of cultivation or adversely affecting the cropping pattern. Such is the case in the Punjab where on account of rapid rise in the ground water table over the past few decades, vast areas have been badly affected and expensive and extensive remedial measures have been necessitated. On the other hand, where more water is withdrawn than is annually replenished, the ground water table gets lowered. Such is the position in Madras, where large-scale pumping of underground water for irrigation has considerably lowered the ground water table with the result that the cost of lift irrigation has been steadily increasing. If this trend were allowed to continue unchecked, the water table may get depressed to an extent that it would render lift irrigation prohibitively expensive and create difficulties even for domestic supplies. All this points to the great importance of systematic and continuous observation of

ground water table in all parts of the country where large-scale exploitation of surface or ground water is being made or is contemplated to be made. In areas where the ground water table has been noticed to be rising, restriction of canal irrigation and resort to lift irrigation might be necessary. Also, it will be necessary to open up drainages and remove obstruction to flood flows. In the case of falling ground water table, it might be necessary to restrict lift irrigation and, where feasible, augment the natural process of replenishment by artificial means. This can be accomplished by diverting surplus water from natural streams and spreading it over adjacent permeable soils; by releasing water from storage reservoirs to natural channels during periods when the channels would otherwise be dry; or by injecting water into wells, shafts or pits.

19. It is of great importance to standardise the method of observation and recording of the ground water data. The subsoil water level rises during the monsoon and, thereafter, continues to fall till the beginning of the next monsoon when it starts rising again. This fluctuation in subsoil water level varies from year to year, depending primarily on the infiltration from rainfall in that particular year, the water drawn out during the corresponding period and additions from seepage. For observing the trend of variations in the ground water level, a watch has to be maintained over a period of years. As such, observations of spring level in the observation wells, would need to be made at least once before the monsoons, say, in April and once after the monsoons in October, each year. However, in areas where there is an acute problem of rising or falling ground water table, as in the Punjab and Madras, observations at closer intervals are indicated. With the data thus collected, subsoil water contour maps should be prepared. A comparison of such contour maps from year to year would reveal where ground water table is rising or falling and the rate at which the change is taking place. With this knowledge, timely remedial measures can be taken where called for and the pattern of water utilisation modified to serve the interests in the best manner. For the observations to be most useful, it is important to select the line of observation wells with care and having made the selection not to change it. Also, the reference point for observation at each observation well should be permanently and firmly fixed and its value recorded with reference to a known near-by survey bench mark.

PRESENT UTILISATION OF GROUND WATER RESOURCES

20. The underground water resources are exploited through tubewells, filter points and open wells. There are about 20,000 private tubewells and filter points and about 5 million open wells in the country, which between them draw about 31 million acre feet (382 m h c m) per annum. In addition, there are about 9000 Government-owned deep tubewells which draw about 4 million acre feet (49 m h cm) per annum. The present annual exploitation of underground water resources in the country is thus roughly estimated at 35 million acre feet (432 m h cm).

ALLOCATION TO VARIOUS USES

21. Competing demands arise where available water is insufficient to satisfy the various requirements. In multiple purpose river valley projects, conflicts arise from multiple uses of water. These conflicts relate to storage space, time of use and discharges. Conflicts for storage space occur if a reservoir of limited capacity is expected to serve divergent purposes like flood control and water conservation. Flood control and water conservation have opposing requirements on the storage capacity. Whereas the needs of flood control demand that adequate reservoir capacity should be kept empty to absorb floods, the interest of water conservancy requires the maximum filling up of the reservoir. Conflicts in time arise in the joint use of storage water where the seasonal use pattern varies from one purpose to another. For example, such a conflict arises in the case of a reservoir which caters for both power load related to the annual peaks. Water requirements for irrigation vary with the season. Irrigation demand also varies with local precipitation. Thus, if water releases are controlled by power, it may mean that a good deal of supply will be wasted when there is no demand for irrigation water, unless other means can be found to conserve it. On the other hand, if water is conserved during periods of low demand for irrigation, power generation will get restricted during that period. In all these cases, either certain sacrifices must be made by various interests or additional costs must be incurred to bring different uses together in a unified and integrated operation of the storage. Conflicts in daily discharge also arise where power and irrigation are derived from a single reservoir. Regulating pools can, however, be used to equalize the flow from the tail race for providing a steady discharge for irrigation.

CO-ORDINATED PLANNING FOR SURFACE AND UNDER-GROUND RESOURCES

22. For rational planning of the use of water resources in an area, both the surface and the under-ground water resources should be viewed together. The exploitation of surface water resources is generally more economical than the underground water resources. But, in certain situations, where surface water has to be conveyed over long distances before it can be used, and underground water resource is available in adequate quantities and at reasonable depth, it would be cheaper and more satisfactory to use the latter. Apart from the initial capital outlay, use of underground water involves recurring cost on pumping and generally higher maintenance and operation charges. Where demands for cheaper surface water for various uses exceed the availability and sufficient underground water is available to fill the gap, it is necessary to specify the uses to which either sources should be put, as otherwise the cheaper source might get utilised for a purpose which can bear a higher cost, leaving the more expensive source for other purposes to which it may prove burdensome.

23. In India, with its predominantly agricultural economy, the major use of water resources has been for irrigation. But rapid strides are now being made in industrial development also. Problems of water supply for industrial uses

have already arisen in several areas notably in the Bihar-West Bengal region. Unless adequate supply of water for industrial and domestic uses is ensured in industrial belts, the development of industries in these areas is likely to get stiffled. It is important that, in such areas, assessment should be made of the total water resources both surface and underground, and a priority of use established, after taking a long-range view of the various requirements such as irrigation, river conservancy, navigation, power generation, industrial and domestic requirements, etc. Needless to say, that municipal requirements would ordinarily have the highest priority amongst the various uses.

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